COMPACT MICRO PULSED PLASMA THRUSTERS ENABLING ATTITUDE CONTROL FOR INTERPLANETARY CUBESAT MISSIONS

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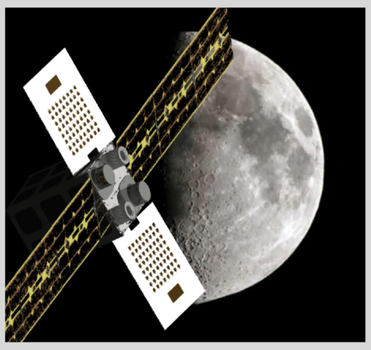

Figure 1 : Artistic illustration of SIRONA with two ion thrusters and the two packs of compact micro PPTs

Abstract

Pulsed Plasma Thrusters (PPTs) were used at the very beginning of the space era, as shown by the Zond 2 mission (1964) [1]. Their physical properties and technical performances have been under study since then, enabling the development of new possibilities for space propulsion and attitude control systems. PPTs represent a simple, low-cost and highly efficient thrust subsystem. Today, CubeSats [2] offer a unique academic and industrial platform to propose and realize new kinds of ambitious missions. Recent examples, like MarCO [3], demonstrate that the space community has seen the arrival of CubeSats as key-players of space exploration beyond low Earth orbit. These CubeSats are the vanguard that will make the exploration of the Moon and Mars possible at a lower cost. However, these complex missions are occurring in regions where the use of conventional CubeSats' magnetorquers is not possible due to a weak or non existent magnetic field.

Although several solutions exist, they appear to have either a low specific impulse (more propellant needed), pressurized tank (too much security constraints for a CubeSat platform) or simply too bulky/heavy. This poster's goal is to respond to those limitations with a new compact micro PPT system for reaction wheels desaturation. To illustrate the potential of this propulsive attitude control system, the developments are shown in the frame of the CubeSat SIRONA (Fig. 1), student project led by the student space center of CentraleSupélec (CS^3) and aiming to conduct science experiments in lunar orbit.

I. SYSTEM DESCRIPTION

Fig. 2 presents the different components of an APPT (Ablative Pulsed Plasma Thruster) propulsion system. A capacitance of a few µF is connected to two copper electrode. A spark plug is placed close to the cathode and a solid propellant slab (PTFE) is placed between the two electrodes. Thanks to a voltage of a few tens of kilovolts, this spark plug triggers and initiates the plasma discharge between the two electrodes. The underlying physical phenomena linked with the spark plug are not fully understood yet and more efforts of the scientific community is needed. One of the leading hypotheses is that the UV radiation generated by the spark plug, tear electrons from the PTFE, thus ionizing the medium, closing the electrical circuit formed by the capacitance and the electrodes, finally allowing the capacitor bank to discharge. The PTFE is then ablated, ionized under the effect of heat and a plasma slice is then formed. The circulation of a current in the circuit allows the appearance of a self-induced magnetic field.

The plasma slice, which closes the circuit, is then subjected to Laplace force and is ejected towards the output of the PPT. The discharge of the capacitance is carried out over a time of about 1 µs and the discharge frequency is about 1 to 2 Hz. The modelling of the system shows that the electric efficiency of the system depends on the initial inductance of the circuit but also on the variation of inductance. Thus, the initial inductance has to be minimized. This explains why the capacitor bank has been connected to the electrodes using two copper rails, enabling the reduction of distances. This choice turned out to be relevant to stiffen the PPT structure and to increase the compactness of the system. The electrodes form a nozzle allowing the acceleration of the particles at the output of the PPT.
The PPT concept has several advantages compared to other solutions such as the absence of warmup time, the easy scalability, a variable thrust level (by changing the frequency of pulses). The use of a solid propellant has several advantages. Tanks or valves are not required, preventing the system from leakage. Compared to liquid or gas, PTFE is more stable, allowing an easy storage and an easy integration of the system on the platform. These elements simplify the design of the system, increasing its reliability.

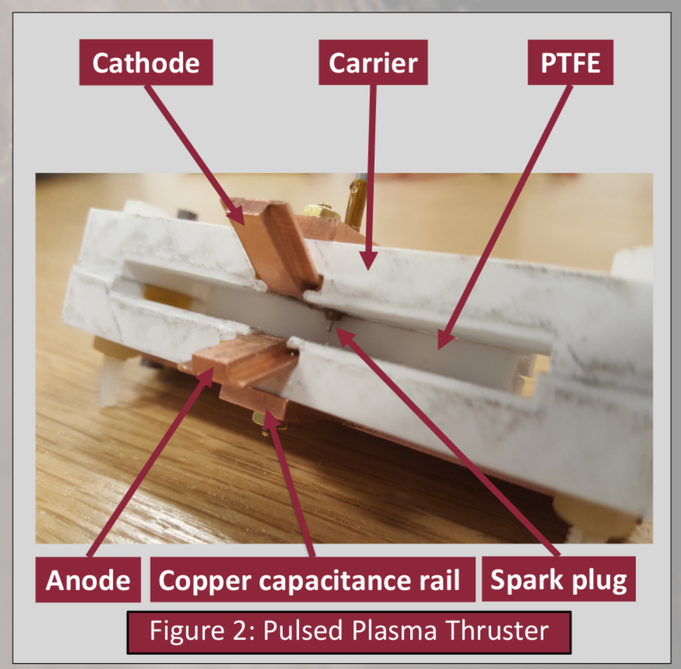

Figure 2: Pulsed Plasma Thruster

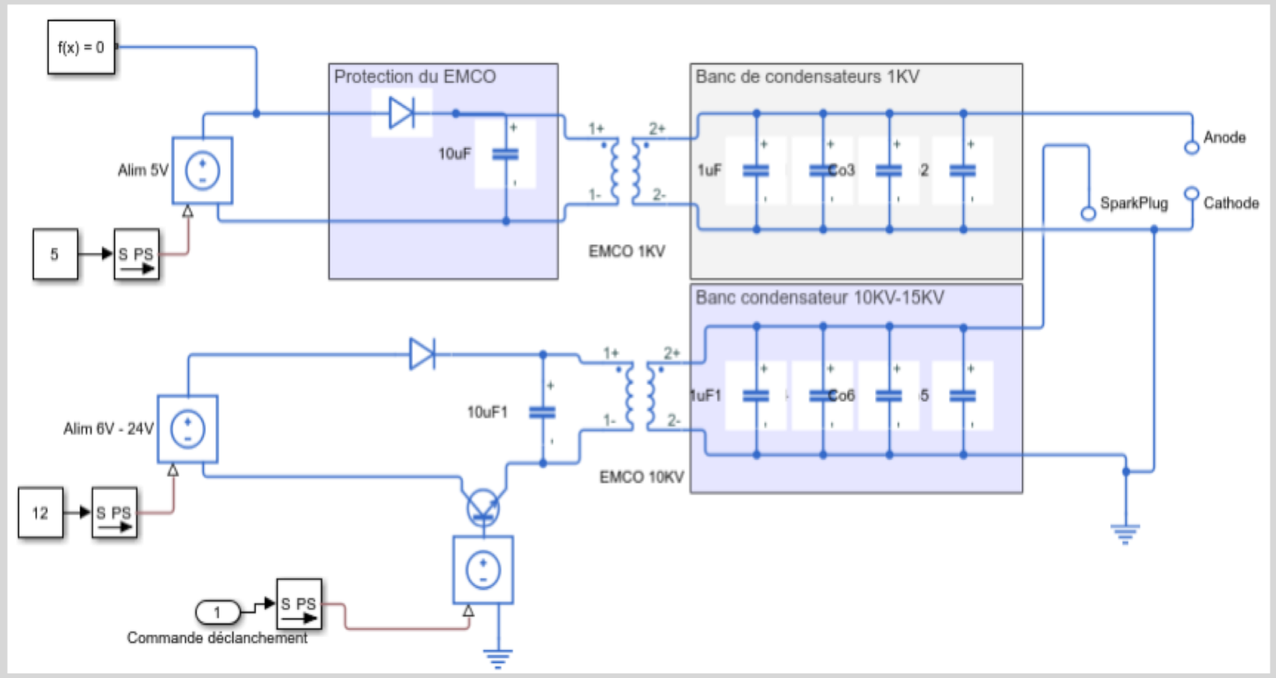

Figure 3: Diagram of the Electronic Power Units

The CubeSat will be equipped with batteries able to deliver a tension of 5V. This tension has to be converted in approximately 1 kV for the discharge capacitance on the one hand and in 10 kV tension for the spark plug initiator on the other hand. Different solutions were available in order to achieve these conversions. Two on-the-shelf components (EMCO) were chosen to achieve these necessary transformations. The electronic circuit schematic is presented in Fig. 3 and the prototype is in the next section in Fig. 4.

II. FINAL CONCEPTUAL DESIGN

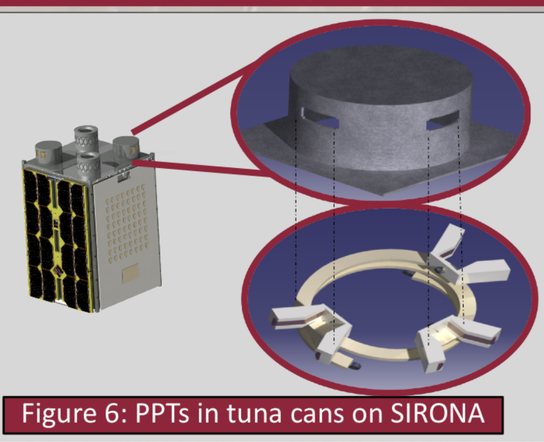

Figure 6: PPTs in tuna cans on SIRONA

In the final design, the goal is to pack 3 PPTs in each of the two available tuna cans (Fig. 6). This configuration allows to control the attitude of the platform in the three axis and thus, to desaturate the momentum wheels when the CubeSat is far from a significant magnetic field.

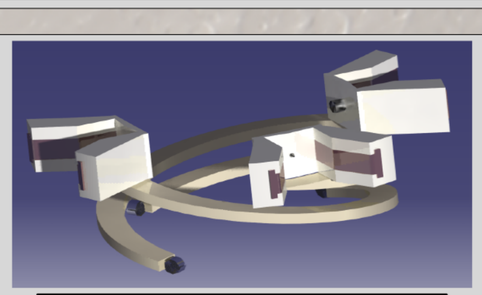

Figure 7: PPTs inside tuna cans

This design enables us to achieve substantial gains regarding compactness and efficiency. Each power unit will be dedicated to a specific pack of PPTs and located between the helicoidal shaped PTFE bars (Fig. 7).

III. PROOF OF CONCEPT

The first test campaign has been performed, both to test the operational use of the spark plug and the capacitor discharge. A power supply delivering a 5 V was used to feed the PCBs dedicated to the conversion of tension (Fig. 4).

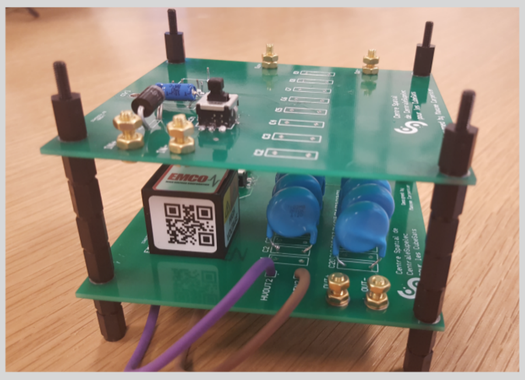

Figure 4: PCBs ensuring the conversion of tension for the spark plug and the capacitor bank

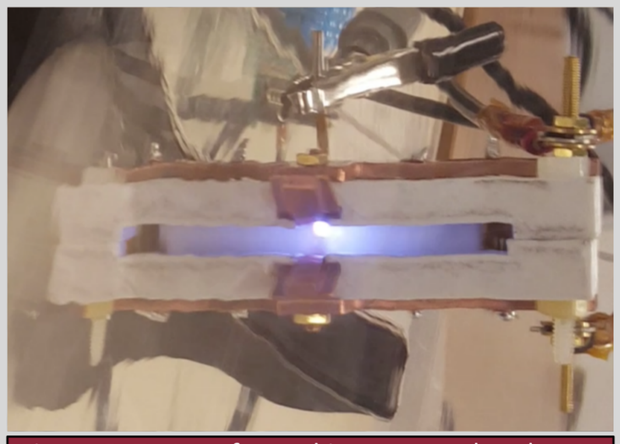

Figure 5: Test performed in vacuum chamber to prove the feasibility of the PPT System at CS^3

Fig. 5 shows the plasma created by the PPT during this first test campaign. Further tests will be conducted to characterize the discharge and fully validate performances of the proposed PPT design in a relevant environment.

Conclusion

The work presented in this poster enabled to produce the PPTs' proof of concept. Further tests will be conducted to validate the performances required for the mission (namely 600s of Isp). Moreover, the realization of the final design will require an optimization of electronics. The complex challenge of adapting CubeSats for interplanetary missions, as it is the case for SIRONA, leads to new fully optimized subsystems, like the compact micro PPTs that will increase the capabilities of stand-alone and long duration nanosatellite missions, thus unveiling new horizons for CubeSats used for deep space exploration.

Acknowledgments

The research leading to these results has received funding and support from THALES ALENIA SPACE. The authors would like to thank the EM2C Laboratory, Erika Jean-Bart, Tanguy Phulpin, Centrale Foundation and the iCubeSat committee for accepting this poster and providing the student fellowship.

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